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TERTIARY FRESH-WATER MOLLUSKS FROM PACIFIC ISLANDS[1]

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ABSTRACT

Two fresh- or brackish-water gastropods, a planorbid (*Gyraulus bikiniensis* Ladd, sp. n.) and a neritid (*Neritilia traceyi* Ladd, sp. n.) are described from the lower Miocene (Tertiary *e*) limestone of Bikini, Marshall Islands. Both were obtained from beds that may be related to the solution unconformity at the top of the Tertiary *e* section. The unconformity was developed at a time when Bikini stood above the sea as a high limestone island that supported a more varied fauna and flora than is found there today.

A river snail (*Clithon corona* Linnaeus) was collected from a marine tidal flat deposit in the lower Miocene (Tertiary *f*) of Fiji. Also in Fiji, a fresh- or brackish-water thiarid (*Melanoides* cf *tuberculatus* Müller) occurs in abundance in a dark shaly material that probably represents an upper Tertiary mangrove swamp or bog.

INTRODUCTION

Deep drilling and detailed field mapping have shown that Tertiary marine deposits are widespread on the islands of the open Pacific. Terrestrial fossils are rare; they include land shells and spores and pollen of a number of land plants but, to date, the only fossil freshwater mollusk has been a single river snail, *Clithon corona*, described from the upper Tertiary of Fiji. A second upper Tertiary snail, *Melanoides* has now been found in Fiji along with fragmentary remains of clams that probably record a fresh- or brackish-water environment. From a deep drill hole on Bikini in the Marshall Islands have come two other non-marine snails, a fresh-water planorbid (*Gyraulus bikiniensis* sp. n.) and a fresh or brackish-water neritid (*Neritilia traceyi* sp. n.), both from lower Miocene (Tertiary *e*) sediments. These mollusks, the only Tertiary examples known from the open Pacific, are described in the present paper and paleoecological aspects are briefly considered.

LOCALITIES

The Marshall Island shells (*Neritilia* and *Gyraulus*) were recovered from lower Miocene (Tertiary *e*) beds in drill hole 2B on Bikini Island (Figs. 1, 2). The Fijian occurrences are from surface exposures of the upper Tertiary Suva Formation on the high island of Viti Levu: the *Clithon* from the type section near sea level on Walu Bay, (Sta. 160, Fig. 3); the *Melanoides* and pelecypod fragments from higher ground in the north central part of the island (Sta. C 136, Fig. 3).

NATURE OF OCCURRENCES

The Bikini shells were picked from drill cuttings. Shells as small as these can, of course, circulate in the drilling fluid, particularly if the fluid be a heavy mud. Under these conditions there is, admittedly, some doubt as to the exact depth from which the shells were derived. It is possible that they may have come from a somewhat shallower horizon. Their preservation indicates clearly, however, that they are fossils, not shells of living forms that fell into the open hole or were pumped in from the mud pits.

The *Clithon* from Fiji was collected from a richly fossiliferous outcrop of conglomerate on Walu Bay at Suva (Sta.

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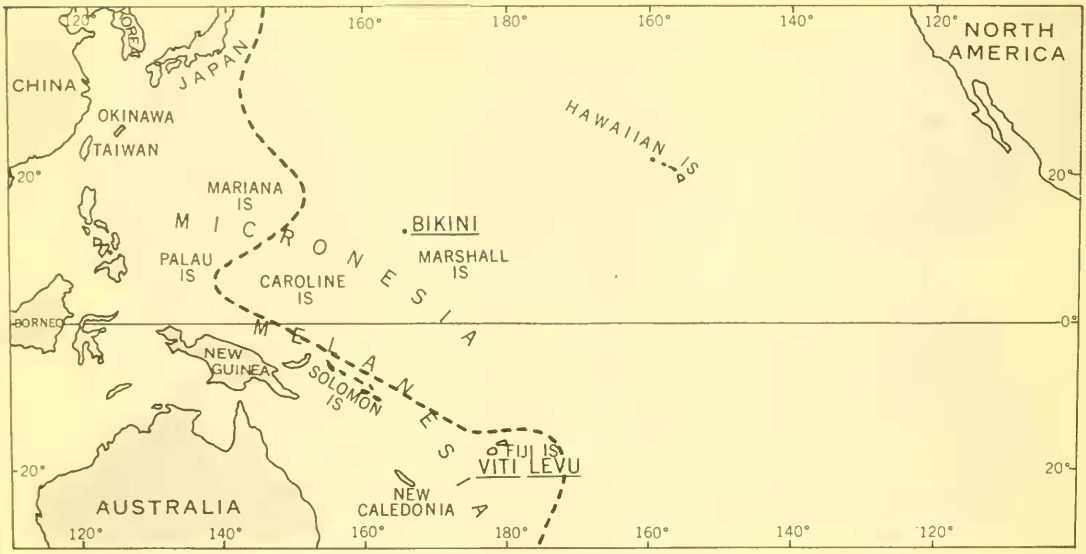

FIG. 1. Index map. Dashed line (Andesite line) marks structural boundary of the Pacific Basin.

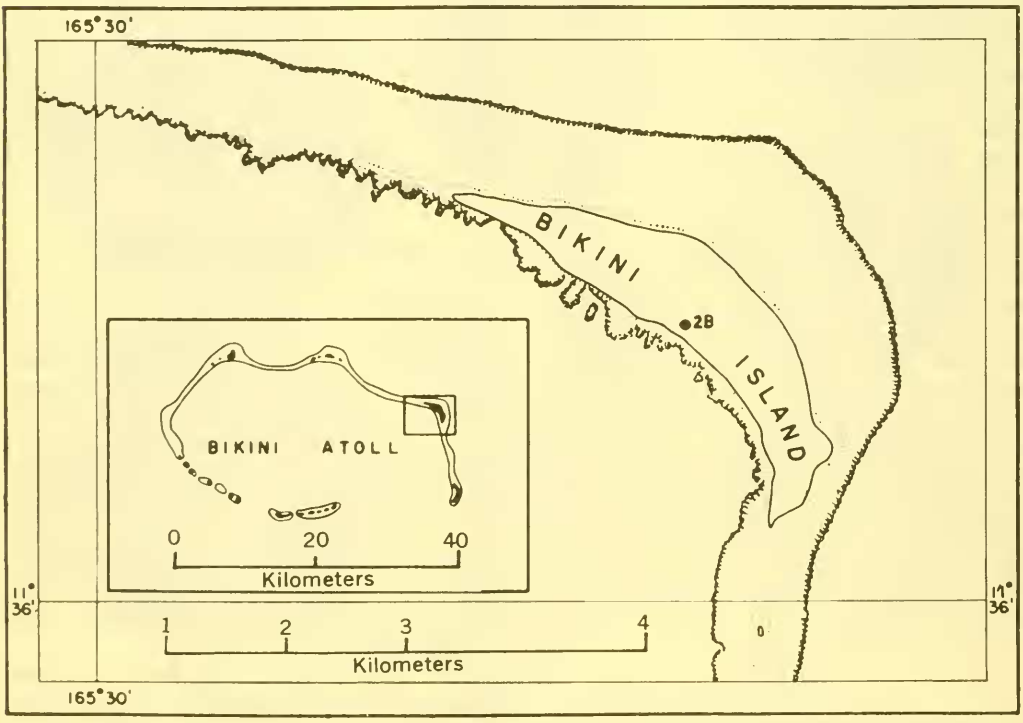

FIG. 2. Sketch map of Bikini, Marshall islands.

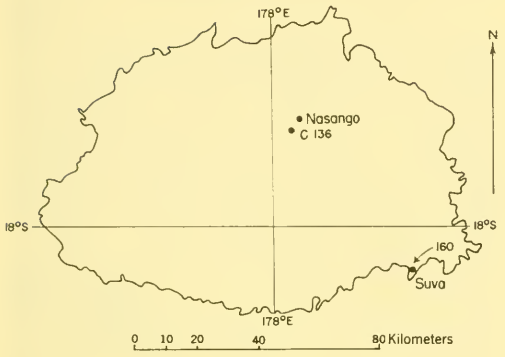

FIG. 3. Sketch map of Viti Levu, Fiji, showing locations of fossil-bearing rocks.

160, Fig. 3). The fauna is shallow-water marine and many of the mollusks and corals are worn, as is the transported river snail.

The numerous specimens of *Melanoides* were obtained from a large boulder of soft shaly material in the bed of Nasaranga Creek near the village of Nasongo in the northern interior of Viti Levu. A friable rock of this type cannot have traveled far from its outcrop in this heavily forested area.

SYSTEMATIC DESCRIPTIONS

Family Neritidae

Genus *Clithon* Montfort (1810, Conchyl. Syst., 2, p 327).

Type (by original designation): *Nerita corona* Linnaeus. Recent, rivers of Asia and Indonesia to Melanesia.

Subgenus *Clithon* sensu stricto
Clithon (*Clithon*) *corona* (Linnaeus)
Pl. 1, Figs. 1-2

Nerita corona Linnaeus, 1758, Syst. Nat. 10th ed., p 777.
Neritina brevispina Lamarck, 1822, Animaux sans vertèbres, 6, pt. 2, p 185.
Theodoxus corona Baker, 1923, Acad. Nat. Sci. Phila. Proc. 75, p 155.
Theodoxus (*Clithon*) *corona* Ladd, 1934, Bishop Mus. Bull. 119, p 208, Pl. 35, Fig. 16; Pl. 36, Fig. 1.
Clithon corona Benthem Jutting, 1959, Treubia, 23, pt. 2, p 275, Figs. 1 and 6 (see additional citations).

A single fossil example of this widely distributed Recent Indo-Pacific fluviatile species was described from the lower Miocene (Tertiary *f*) Suva Formation of Viti Levu Ladd, 1934: 208). The species lives in Fiji today and Recent shells exhibit considerable variation in the development of the spiral ridge and its spines. The Fiji fossil clearly falls within the range exhibited by Recent shells. The species has also been recorded from the upper Pliocene and Pleistocene of Java (Benthem Jutting, 1937: 102, Table 4; 1956: 276).

Genus *Neritilia* Martens (in Martini and Chemnitz, 1879, Systematisches Conchylien-Cabinet, Bd. 2, Abt. 10, p 18).

Type (by original designation): *Neritina rubida* Pease. Recent freshwater, Tahiti.

Neritilia traceyi Ladd, sp. n.
Pl. 1, Figs. 3, 4

Minute, obliquely elliptical, smooth, thick; aperture lunate; inner lip convex, its margin edentulous; columellar deck convex, heavily callused, posterior margin of callus broadly convex.

Measurements of the holotype, USNM[2] 648336: height 1.9 mm, diameter 2.5 mm.

Occurrence: Holotype (only specimen) from drill hole 2B, Bikini Atoll at depth of 2154-2165 feet; age, lower Miocene (Tertiary *e*). The genus has not previously been reported as fossil.

N. traceyi has the edentulous inner lip that is characteristic of *Neritilia* but the lip margin is convex, whereas in typical *Neritilia* it is straight. The inner lip of the fossil is more heavily callused than that of the type-species, *N. rubida* (Pease), but a callused lip comparable to that of

[2]U. S. National Museum Catalog number.

the fossil is present on a small brackish-water *Neritilia* found in abundance, by J. P. E. Morrison, near the mouths of coastal rivers in New Caledonia. The outer lip of the fossil is worn and this accounts, in part, for the apparent great thickness of the shell and the shortness of its elliptical outline.

Family Thiaridae

Genus *Melanoides* Olivier (1804, Voyage dans l'Empire Othoman, l'Egypte et la Perse, 3, p 69).

Type (by monotypy): *Melanoides fasciolata* Olivier = *Nerita tuberculata* O. F. Müller. Recent Coromandel, India.

Melanoides (*Melanoides*) cf *tuberculatus* (Müller)
Pl. 1, Fig. 5

Small, slender; whorls moderately convex, somewhat flattened immediately below impressed suture; aperture elongate-oval, angular above, rounded below; imperforate; peristome incomplete. Sculpture consisting of spiral cords, 4-7 on penultimate whorl; on some shells the spirals are crossed by weak or moderately developed axials that give the shell a clathrate appearance, with the intersections beaded in some instances; in a few shells the axials are developed into strong curved ridges (Fig. 5).

Measurements of the figured specimen, USNM 648447: height (incomplete) 3.9 mm; diameter (body whorl incomplete) 1.4 mm.

Occurrence: Abundant at Station C 136; boulder in Nasaranga Creek about 5 kilometers southwest of Nasongo, Viti Levu, Fiji; age, probably upper Tertiary. *M. tuberculatus* was originally described as a Recent shell from Coromandel, India. The species has been widely reported from Asia Minor, Africa, India, Malaya through southern China, Indonesia, north Australia, and from a number of Pacific islands, including Fiji (Germain, 1932: 55). Fossil shells have been reported from the upper Miocene (Martin, 1905: 238), and the Pliocene and Pleistocene of Java (Benthem Jutting, 1956: 416).

According to Mrs. van Benthem Jutting, who described Recent shells from Java and other Indonesian islands (1956: 415; 1958: 325), *M. tuberculatus* generally is found in fresh water but occasionally in brackish waters. It seems to prefer slowly running water but has been found living in stagnant, even polluted, waters; it also occurs in swamps.

The Fijian fossils almost certainly represent the exceedingly variable and widely distributed *M. tuberculatus*, but on none of the numerous fossils is the apex or the aperture complete or well preserved. The fossils have been compared with Recent shells from many areas. The fossils are smaller than most Recent shells and most of the fossils show a well developed flattened area immediately below the suture. An area of this sort is found on some Recent shells.

Family Planorbidae

Genus *Gyraulus* Charpentier (1837, Catalogue des mollusques terrestres et fluviatiles de la Suisse, Neue Denkschr. Allg. Schweiz. Gesell., 1(2): 21).

Subgenus *Gyraulus* sensu stricto

Type (by subsequent designation, Dall, 1870, Ann. Lyceum Nat. Hist. 9, p 351): *Planorbis albus* Müller. Recent, rivers of Europe.

Gyraulus* (*Gyraulus*) *bikiniensis
Ladd, sp. n.
Pl. 1, Figs. 6-8

Shell minute, thick; 2 1/2 visible rounded whorls coiled in a discoid spiral that is flattened below; suture deep, apex sharply sunken, aperture semi-oval, oblique, its lower margin projecting forward; peristome incomplete, slightly callused both above and below at its junction with the penultimate whorl. Sculpture consisting of fine curved growth lines that are more conspicuous near the aperture than elsewhere.

Measurements of the holotype, USNM 648448: height 1.0 mm, diameter 2.0 mm.

Occurrence: Holotype (only specimen) from drill hole 2B, Bikini Atoll, at depth of 1723-1734 feet; age, lower Miocene (Tertiary e).

G. bikiniensis is characterized particularly by its height, which is equal to one-half the diameter, and by the absence of spiral sculpture and any trace of a peripheral keel. The single specimen may be immature.

It is proportionately much higher than *G. albus*, the type species. It more nearly resembles *G. brongersmai*, a Recent species described from West New Guinea (Benthem Jutting, 1963: 495, Figs. 50a, 50b) but the Recent shell has more numerous whorls, a peripheral keel and a less deeply sunken apex.

In the Pacific area, a number of species of *Gyraulus* have been reported from the western islands (Japan, Philippines, New Guinea). Three species have been reported from the islands of the open Pacific: *G. singularis* (Mousson) from Fiji (Germain 1923: 146); *G. montrouzieri* (Gassies) from the New Hebrides (Solem 1959: 164) and New Caledonia (Germain, 1923: 147); and *G. rossiteri* (Crosse) from the Loyalty Islands (Crosse 1880: 142) and New Caledonia (Solem, 1961: 440). None of these species closely resembles the Miocene *G. bikiniensis* from the Marshall Islands.

Pelecypods

Associated with the numerous crushed shells of *Melanoides* are a number of small fragments of pelecypod shells. Most of these show growth lines, but these are not diagnostic. A few retain parts of a dark-brown periostracum. One fragment is a badly eroded hinge area that may represent the left valve of a small *Batissa*, a genus common in the fresh and brackish waters of Viti Levu today. Another fragment with close-set rounded ribs and an internal pearly luster probably represents a mytilid, possibly a species of *Arcuatula*, an intertidal and brackish-water group.

PALEOECOLOGY

Three distinct environments seem to be represented by the shells described above: (1) a lower Miocene elevated reef island in the Marshalls, (2) a Miocene tidal flat deposit in Fiji, and (3) an upper Tertiary mangrove swamp or bog, also in Fiji.

(1) The planorbid, *Gyraulus*, and the *Neritilia* from drill hole 2B on Bikini were recovered from cuttings below the solution unconformity that marks the top of Tertiary *e* beneath both Bikini and Eniwetok. These relations are clearly portrayed by Schlanger (1963: 995: Fig. 308). The unconformity is a leached interval in which original aragonite has been replaced by calcite (Ladd and Tracey, 1957: 218). The zone is thought to record a time when the atoll stood some hundreds of feet above the sea and underwent prolonged subaerial erosion. The drill hole that furnished the fresh-water shells also yeilded a high-island land snail, *Ptychodon subpacificus* (Ladd, 1958: 189) at a depth of 1807-1818 feet, an interval lying between the *Gyraulus* occurrence (1723-1734 feet) and the *Neritilia* bed (2154-2165 feet).

The solution zone in drill hole 2B extends from about 1100 feet to about 1600 feet (Schlanger, 1963: 995, Fig. 308). I think that the 3 non-marine shells, all small and showing some evidence of wear, occurring 100 to 500 feet below the solution zone, lived at the time the beds were being leached. Bikini at this time is thought to have stood above the sea with high island vegetation and with pools of fresh or brackish water near sea level that could have furnished a suitable environment for the planorbid and the *Neritilia*. One brackish pool (probably artificial, at least in part) exists on Bikini Island today. The surface of the pool lies just above sea level; it is fed by the thin Ghyben-Herzberg lens of fresh water that underlies the island (Emery et al., 1954: 50, 204). No species of *Gyraulus* or *Neritilia* were found living on Bikini and nearby atolls during extensive field work by the Geological Survey nor were any land shells of the *Ptychodon* type discovered. How-

ever, in early Miocene times, when the island was larger and stood higher, natural pools of fresh and brackish water apparently existed, as they do on many elevated limestone islands today.[3]

Living planorbids of the *Gyraulus* type have been reported from all continents. They are abundant in Indonesia and the Philippines and, as noted above (p 9), have been reported from the New Hebrides, New Caledonia, Fiji, and other Pacific islands. None, however, have been reported living in the Marshall Islands. They live in fresh, mostly stagnant, water and also occur in sluggish streams (Benthem Jutting 1956: 463). Small and fragile shells of *Gyraulus* were dreged from depths of about 300 to 700 fathoms in Indonesian waters by the U. S. Fish Commission steamer *Albatross* (Specimens in USNM collection). Many of the living animals are remarkably hardy. They inhabit small pools that may become nearly or completely dry during periods of dry weather (Baker, 1945: 17). According to Kew, planorbids have survived even after being frozen in solid ice for a period of a month. This suggested a new means of dispersal across arms of the sea (Kew, 1893: 42), but tropical species can hardly take advantage of this uncertain means of dispersal. They manage, however, to get around. Living in the shallow waters of ponds favored by wading birds, they do, on occasion, attach themselves to the feathers of such a bird and are transported. Roscoe has reported finding representatives of 3 fresh-water snail families (one a planorbid, *Helisoma*) on a White-faced Glossy Ibis (Roscoe, 1955).

Neritilia has not been found living in the Marshall Islands in spite of intensive collecting there. It has been collected from many other island groups in the southwest Pacific, the nearest to the Marshall Islands being Samoa and Fiji. The Miocene shell from Bikini appears to be the first fossil occurrence.

(2) In Fiji the single specimen of the river snail, *Clithon corona* was collected from the conglomerate layer that underlies reef limestone in the type section of the Miocene (Tertiary *f*) Suva Formation on Walu Bay, Viti Levu. The conglomerate ranges in thickness from a few inches to more than 10 feet. It contains well rounded pebbles and boulders of several types of igneous rocks as much as 6 inches in diameter, along with coral heads. The corals are water worn, as are many of the shells of about 50 species of marine mollusks that occur with them. The mollusks are reef and reef-flat species and the worn coral heads also suggest a reef flat or shore platform. The well rounded igneous boulders and the worn river snail were probably brought to the flat by a stream descending from a steeply rising coast. Several such streams enter Suva Harbor in this area today and river snails of several sorts are found in abundance on boulders in their beds.[4]

(3) The Fijian sample that yielded the numerous crushed specimens of the fresh-water snail, *Melanoides*, and fragments of at least 2 pelecypods is a soft, nearly black shaly material whose dark color distinguishes it from the buff to green tuffs that blanket much of the large island of Viti Livu. The sample contains abundant coaly black material that, on ignition, leaves a well-bedded residue of the shape and size of the original particle. The black organic matter seems to impregnate a fine-grained sediment. The rock also contains microscopic gypsum which may represent pyrite that has reacted with shell remains under oxidizing conditions (Milton, Charles, written

[3]Numerous specimens of an undescribed *Iravadia* that may have lived in brackish water were recovered from Miocene beds in all 3 deep holes on Eniwetok at depths of 670-937 feet. Most of them are in beds referred to Tertiary *g* but a few are from the underlying Tertiary *f*. All are in the unleached zone between 2 solution unconformities (Schlanger, 1963: 995). The type-species of *Iravadia* lives in the brackish waters of the Irrawaddy delta but other species apparently are near-shore marine.

[4]A review of the molluscan fauna of Fiji, including land and fresh-water types, has been published by Germain (1932).

communication, 1963). The dark sediments also contains a good deal of pollen and the spores of land plants. Prevalent forms are true mangrove (*Rhizophora*) and a mangrove habitat genus, *Sonneratia*. Also present are a strand plant (*Terminalia* or *Cambretum*), ferns (including *Pteridium*) and upland forest plants (Leopold, Estella, written communication, 1964). All in all, the dark rock seems to represent a fine clay sediment laid down in the fresh or slightly brackish waters of a coastal swamp or bog.

FRESH-WATER FOSSIL MOLLUSKS FROM THE ISLANDS OF THE OPEN PACIFIC

The oldest identified fresh-water mollusk in the Pacific Island area is a gastropod from the Upper Cretaceous of New Caledonia, described by Avias and Rey (1958) as *Pyrgulifera glypta* (Rey, 1961: 7-10, Pl. 1, Figs. 1, 2). In 1958, Freneix (p 195) noted fragments of pelecypods from an argillaceous schist of Late Cretaceous age from New Caledonia. The 2 incomplete specimens were questionably referred to the Unionidae but it was stated that they occurred with gastropods and other pelecypods that appeared to be marine.

In the Tertiary, the oldest fresh-water mollusks from the islands are the *Neritilia* and the *Gyraulus* from Bikini, here described. The *Clithon* and the *Melanoides* from Fiji are somewhat younger.

Though fresh-water pelecypods are found living in several island groups in the open Pacific today, their fossil record in these places is meager. It consists of the questionable fragments from New Caledonia and the incomplete shells from C136 in Fiji, already mentioned. The Fijian fossils occur with fresh-water snails, but the pelecypods are too incomplete for certain generic determination.

Fossil pelecypods from Fiji supposed to be of fresh-water origin were described by A. Morley Davies who, with some reservations, gave the name of *Nodularia vitiensis* to rather poorly preserved internal molds of a pelecypod collected from an outcrop near Nasongo in Viti Levu (Fig. 3). With these fossils he recognized fragmentary molds of a small holostome gastropod, thought possibly to be a *Vivipara* (Matley and Davies, 1927: 72-75). Later, having examined photographs and descriptions of better material collected in the same area by Ladd, Davies agreed that the species thought to be a *Nodularia* was definitely mactroid and marine (Davies, 1930).

In Indonesia with its large continental islands the earliest records of fresh-water mollusks are from the Eocene and Miocene (Van der Vlerk 1931: 254, 262; Van Es, 1931: 52, 136). As Mrs. van Benthem Jutting points out, however, in Java the bulk of the non-marine mollusks does not appear prior to the middle Pliocene (1937: 86).

CONCLUSIONS

The fossil occurrences here described indicate that fresh and brackish-water environments existed on widely separated island areas in the southwest Pacific at least as early as the lower Miocene. This is not surprising in the case of Fiji whose large, mountainous, and geologically complicated islands are known to date back at least to the Eocene (Cole, 1960). The 2 mollusks described from the Marshall Islands, an area where no fresh-water shells live today, are of particular interest because they occur in a Miocene section which has also yielded a species of high-island land shell (Ladd, 1958) and an assemblage of pollen and spores pointing to a richer and more varied flora than is found in the area today (Leopold, in press). These paleontologic data all support a conclusion based on a petrographic study of the limestones, namely that during the Miocene, Bikini and nearby Eniwetok stood higher above the sea than they do today (Schlanger, 1963).

ACKNOWLEDGMENTS

The sample from northern Viti Levu that yielded the *Melanoides* and associated fossils was collected by Peter Rodda of the Geological Survey Department in Fiji. This sample was examined petrographically by Charles Milton and palynologically by Estella Leopold, both of the U. S. Geological Survey.

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RESUMEN

MOLUSCOS TERCIARIOS DE AGUA DULCE DE LAS ISLAS DEL PACIFICO

Dos gastrópodos de agua dulce o salobre, un planórbido (*Gyraulus bikiniensis* sp. n.) y un nerítido (*Neritilia traceyi* sp. n.) se describen, procedentes del calcareo del Mioceno inferior (Terciario *e*) de Bikini en las Islas Marshall. Ambos fueron obtenidos en estratos que pueden estar relacionados con la discordancia erosiva en el techo de la seccion *e* del Terciario. La discordancia se desarrolló en una época cuando Bikini emergía sobre el océano como una alta isla de caliza que mantenia una fauna y flora más variada que la de hoy.

Un caracol fluvial (*Cliton corona* L.) se colectó en un depósito de baja marea del Mioceno inferior (Terciario *f*) de Fiji. También en Fiji, un tiárido dulceacuícola o salobre (*Melanoides* cfr. *tuberculatus* Mull.) aparece en abundancia en materiales pizarrosos obscuros que probablemente representa un pantano de mangrove del Terciario superior.